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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No. ERT-008

First Inventor or Application Identifier Roy T. Hashimoto

Title "Outward Facing Camera System For Environment Capture"

Express Mail Label No. EL405561900US

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents

1. ☐ * Fee Transmittal Form (e.g., PTO/SB/17)
(Submit an original and a duplicate for fee processing)
2. ☒ Specification [Total Pages 22]
(preferred arrangement set forth below)
 - Descriptive title of the Invention
 - Cross References to Related Applications
 - Statement Regarding Fed sponsored R & D
 - Reference to Microfiche Appendix
 - Background of the Invention
 - Brief Summary of the Invention
 - Brief Description of the Drawings (if filed)
 - Detailed Description
 - Claim(s)
 - Abstract of the Disclosure
3. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 9]
4. Oath or Declaration [Total Pages]
 - a. ☐ Newly executed (original or copy)
 - b. ☐ Copy from a prior application (37 C.F.R. § 1.63(d))
(for continuation/divisional with Box 16 completed)
 - i. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b)

NOTE FOR ITEMS 1 & 3: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).

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5. ☐ Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
 - a. ☐ Computer Readable Copy
 - b. ☐ Paper Copy (identical to computer copy)
 - c. ☐ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

7. ☐ Assignment Papers (cover sheet & document(s))
8. ☐ 37 C.F.R. § 3.73(b) Statement of Power of Attorney (when there is an assignee)
9. ☐ English Translation Document (if applicable)
10. ☐ Information Disclosure Statement (IDS)/PTO-1449 [Copies of IDS Citations]
11. ☐ Preliminary Amendment
12. ☒ Return Receipt Postcard (MPEP 503)
(Should be specifically itemized)
13. ☐ * Small Entity Statement(s) [Statement filed in prior application Status still proper and desired (PTO/SB/09-12)]
14. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
15. ☐ Other: _____

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☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP)

of prior application No. _____

Prior application information Examiner _____

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 1c714 U.S. PTO

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jc625 U.S. PTO
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1 OUTWARD FACING CAMERA SYSTEM FOR ENVIRONMENT CAPTURE

2
3 Roy T. Hashimoto
4

5 CROSS-REFERENCE TO RELATED APPLICATIONS

6 This application relates to co-pending application
7 serial no. 09/505,337, entitled "POLYGONAL CURVATURE MAPPING
8 TO INCREASE TEXTURE EFFICIENCY", by Hashimoto, et. al.,
9 filed February 16, 2000, owned by the assignee of this
10 application and incorporated herein by reference.
11

12 FIELD OF THE INVENTION

13 The present invention relates image capturing. More
14 specifically, the present invention relates to multi-camera
15 systems configured for environment capturing.
16

17 BACKGROUND OF THE INVENTION

18 As the processing power of microprocessors and the
19 quality of graphics systems have increased, environment
20 mapping systems have become feasible on personal computer
21 systems. Environment mapping systems use computer graphics
22 to display the surroundings or environment of a theoretical
23 viewer. Ideally, a user of the environment mapping system
24 can view the environment at any angle or elevation. Fig. 1
25 illustrates the construct used in conventional environment
26 mapping systems. A viewer 105 (represented by an angle with
27 a curve across the angle) is centered at the origin of a
28 three dimensional space having x, y, and z coordinates. The
29 environment of viewer 105 (i.e., what the viewer can see) is
30 ideally represented by a sphere 110, which surrounds viewer
31 105. Generally, for ease of calculation, sphere 110 is
32 defined with a radius of 1 and is centered at the origin of

1 rectangular image 310 is slightly larger than the polyhedral
2 face to allow some overlap between the various cameras of
3 the camera system. The overlap allows for minor alignment
4 problems which may exist in the camera system. An
5 environment capture system would only use the data within
6 the faces of the polyhedron while the rest of rectangular
7 image 310 is not used. Thus, only a small portion of the
8 image data captured by each camera is utilized to generate
9 the environment map. Consequently, even the use of multiple
10 cameras arranged using regular polyhedrons may not provide
11 enough resolution for quality environment mapping systems.
12 Hence, there is a need for an efficient camera system for
13 use with environment mapping and immersive videos.

14 15 SUMMARY OF THE INVENTION

16 Accordingly, the present invention provides an
17 efficient camera system that utilizes the asymmetry of
18 conventional camera to efficiently capture environments. In
19 one embodiment of the present invention, an outward facing
20 camera system includes a plurality of equatorial cameras.
21 The equatorial cameras face radially outward from an origin
22 and are located in or near a plane. Generally, the
23 equatorial cameras are distributed evenly about the origin
24 so that each equatorial camera is offset from an adjacent
25 camera by the same equatorial adjacent angle. The outward
26 facing camera system also includes a plurality of polar
27 cameras tilted above the plane. Generally, the polar
28 cameras also face radially outward from the origin and are
29 all tilted by the same equatorial offset angle. However,
30 some embodiments may include polar cameras having different
31 equatorial offset angles.

1 The equatorial offset angle is chosen to insure
2 complete camera coverage of an environment. Therefore, the
3 equatorial offset angle is chosen to eliminate gaps between
4 the fields of view of the polar cameras and the equatorial
5 cameras. Thus, the equatorial offset angle is generally
6 selected to cause some overlap between the field of view of
7 the polar cameras and the equatorial cameras. The outward
8 facing camera system can also include one or more polar
9 cameras tilted below the plane. The present invention will
10 be more fully understood in view of the following
11 description and drawings.

12
13 BRIEF DESCRIPTION OF THE DRAWINGS

14 Fig. 1 is a three-dimensional representation of a user
15 and an environment.

16 Fig. 2(a) is a three-dimensional representation of an
17 environment surrounded by a cube.

18 Fig. 2(b) is a three-dimensional diagram of a
19 conventional camera system based on a cube.

20 Fig. 3(a)-3(d) illustrates inefficiencies of polyhedron
21 faces and rectangular image capture.

22 Fig. 4 is a three-dimensional diagram of part of an
23 asymmetrical camera system in accordance with one embodiment
24 of the present invention.

25 Fig. 5(a) is a three-dimensional diagram of an
26 asymmetrical camera system in accordance with one embodiment
27 of the present invention.

28 Fig. 5(b) is a diagram of part of an asymmetrical
29 camera system illustrating overlapping fields of view.

30 Fig. 5(c) is a conceptual diagram illustrating fields
31 of view for a cameras system an accordance with one
32 embodiment of the invention.

1 Fig. 5(d) is a conceptual diagram illustrating fields
2 of view for a cameras system an accordance with one
3 embodiment of the invention.

4 Fig. 6(a)-6(c) are conceptual diagrams of fields of
5 view to illustrate some benefits of rotated fields of view.

6 Fig. 7 is a three-dimensional diagram of an
7 asymmetrical camera system in accordance with one embodiment
8 of the present invention.

9
10 DETAILED DESCRIPTION

11 As explained above, camera systems for environment
12 mapping should have a spherical field of view to capture the
13 entire environment around a viewer. Symmetrical camera
14 systems based on regular polyhedrons are inefficient because
15 conventional cameras typically produce rectangular images.
16 Thus, much of the image data captured by the cameras of
17 symmetrical camera systems are not used by the environment
18 mapping system.

19 In accordance with the present invention, asymmetrical
20 camera systems are adapted to utilize a greater proportion
21 of the image data from each camera as compared to
22 symmetrical camera systems, which are based on regular
23 polyhedrons. Figs. 4, 5(a), and 6 show various parts of a
24 camera system 400 in accordance with one embodiment of the
25 present invention. Camera system 400 includes a plurality
26 of equatorial cameras 410, 420, 430, and 440. In camera
27 system 400, four equatorial cameras are used. However,
28 other embodiment of the present invention may use a
29 different number of equatorial cameras. As used herein,
30 equatorial cameras refer to a set of cameras in or near an
31 equator of sphere 110. For convenience and clarity,

1 equatorial cameras are described as being in or near the XY
2 plane.

3 The plurality of equatorial cameras face radially
4 outward from the origin and should be distributed evenly
5 about the origin. Each equatorial camera is offset from an
6 adjacent camera by an equatorial adjacent angle. For
7 example, as shown in Fig. 4, camera 410 and camera 420 are
8 offset by equatorial adjacent angle 415. As used herein, a
9 first camera is adjacent to a second camera, if the field of
10 view of the first camera overlaps the field of view of the
11 second camera. Generally, the equatorial adjacent angle
12 should equal 360 degrees divided by the number of equatorial
13 cameras. Thus, when the plurality of equatorial cameras
14 includes 4 cameras, the equatorial adjacent angle is 90
15 degrees. For clarity, equatorial cameras 410, 420, 430, and
16 440 are shown to be on the X and Y axes of Fig. 4.
17 Specifically, camera 410 is located on the positive Y axis
18 pointing in the positive Y direction, camera 420 is on the
19 positive X axis pointing in the positive X direction, camera
20 430 is on the negative Y axis pointing in the negative Y
21 direction, and equatorial camera 440 is on the negative X
22 axis pointing in the negative X direction.

23 The number of equatorial cameras in a camera system is
24 dictated by the field of view of the cameras used in the
25 camera system. A camera C has a rectangular field of view,
26 for convenience the dimension of the field of view are
27 called a horizontal field of view C_H and a vertical field
28 of view C_V . The full rectangular field of view is labeled
29 with reference name C_F . Horizontal field of view C_H is
30 defined with respect to the XY plane. Vertical field of
31 view is defined with respect to ZX plane or the ZY plane.
32 In general, the horizontal field of view of each equatorial

1 camera should be greater than 360 divided by the number of
2 equatorial cameras. For example, a specific embodiment of
3 camera system 400 a camera system includes four equatorial
4 cameras each with a horizontal field of view of
5 approximately 104 degrees and a vertical field of view of
6 approximately 76 degrees. As used herein, field of view is
7 generally defined with respect to the origin. However, when
8 giving specific fields of view for cameras, the field of
9 view is with respect to the camera lens. By allowing
10 overlap of the fields of view this slight discrepancy is
11 inconsequential and can be ignored.

12 Some embodiments of the present invention may tilt the
13 equatorial cameras slightly out of the XY plane. Thus the
14 equatorial cameras may have an equatorial tilt angle. For
15 embodiments where the equatorial cameras are in the XY
16 plane, the equatorial tilt angle is equal to zero.

17 As illustrated in Fig. 5(a), camera system 400 includes
18 a first plurality of polar cameras. Specifically, camera
19 system 400 includes polar cameras 510, 520 and 530 in the
20 first plurality of polar cameras. As used herein, a polar
21 camera is a camera that is tilted above or tilted below the
22 plurality of equatorial cameras. Fig. 5(a) is drawn from
23 the perspective of looking down the Z axis with the positive
24 Z axis coming out of the page. Each polar camera faces
25 radially outward and is tilted out of the XY plane by a
26 equatorial offset angle (see Fig. 5(b)). The equatorial
27 offset angle is dependent on the vertical field of view the
28 equatorial cameras and the polar camera. In camera system
29 400 equatorial camera 440 and polar camera 510 are along the
30 negative X axis. However, some embodiments of the present
31 invention do not align any of the polar cameras with an
32 equatorial camera.

1 The practical maximum and minimum limit of an
2 equatorial offset angle 514 is determined with reference to
3 Fig 5(b) for camera systems in which the field of view of
4 the polar cameras and equatorial cameras are aligned with
5 the XY plane. Furthermore, the following explanations are
6 made based on rectangular projections of the field of view
7 of the various equatorial and polar cameras. In actual use,
8 the rectangular projections do not produce rectangular
9 fields of view on sphere 110. Thus, many small inaccuracies
10 exist in the following calculations of equatorial offset
11 angles. However, by allowing a small but significant
12 overlap between the fields of view, these small inaccuracies
13 can be ignored. Actual camera projections on a sphere 110
14 can be generated using 3-D projection system such as
15 Powerstitch™ by Enroute Inc., which is available for
16 purchase over the internet at "<http://www.enroute.com>".

17 Fig 5(b) is drawn from the perspective of looking down
18 the Y axis with the negative Y axis coming out of the page.
19 Furthermore, for clarity, only equatorial camera 440 and
20 polar camera 510, which are offset by equatorial offset
21 angle 514, are shown in Fig. 5(b). Equatorial camera 440
22 has a vertical field of view 440_V. Polar camera 510 has a
23 vertical field of view 510_V. To ensure complete coverage
24 of the environment, vertical field of view 510_V and
25 vertical field of view 440_V should overlap. Furthermore,
26 vertical field of view 510_V should extend to the Z axis.

27 Since both the vertical and horizontal field of view of
28 a camera is centered about the center of the camera, half of
29 vertical field of view 440_V extend above the XY plane.
30 Similarly half of vertical field of view 510_V extends
31 radially from the center of polar camera 510 towards
32 equatorial camera 440. Thus, equatorial offset angle 514

1 must be less than half of vertical field of view 440_V plus
2 half of vertical field of view 510_V to insure overlap of
3 vertical fields of view 440_V and 510_V. For embodiments of
4 the invention having a non-zero equatorial tilt angle, the
5 equatorial tilt angle can be added to the maximum limit of
6 equatorial offset angle 514.

7 As explained above, vertical field of view 510_V should
8 extend to the Z axis to provide complete coverage of the
9 environment. Thus, equatorial offset angle 514 must be
10 greater than 90 degrees minus half of vertical field of view
11 510_V. In one embodiment of the present invention, both
12 vertical fields of view 440_V and 510_V are equal to
13 approximately 76 degrees. Thus, equatorial offset angle 514
14 has a upper limit of 76 degrees (i.e. $76/2 + 76/2$) and a
15 lower limit of 52 degrees (i.e. $90 - 76/2$). In a specific
16 embodiment of camera system 400, the equatorial offset angle
17 is equal to approximately 56 degrees.

18 Each polar camera is separated from an adjacent polar
19 camera by a polar adjacent angle which is measured parallel
20 with the XY plane, such as polar adjacent angle 515 (Fig.
21 5(a)) separating polar cameras 510 and 520. In most
22 embodiments of the present invention, the polar cameras of
23 the first plurality of cameras are distributed evenly, thus
24 the polar adjacent angles are all approximately equal to 360
25 degrees divided by the number of polar cameras in the first
26 plurality of polar cameras. Thus, for example in a specific
27 embodiment of camera system 400, cameras 510, 520, and 530
28 all have polar adjacent angles equal to approximately 120
29 degrees. The number of polar cameras required for full
30 environment coverage is dependent on the vertical field of
31 view equatorial camera and horizontal field of view in the
32 polar cameras. Specifically, a practical estimate of the

1 number of polar cameras required for full environment
2 coverage is an integer value greater than or equal to 360
3 degrees multiplied by the cosine of half the vertical field
4 of view of the equatorial camera divided by the horizontal
5 field of view of the polar camera.

6 The derivation of the number of polar cameras is
7 conceptually explained with reference to Fig. 5(c) and 5(d).
8 As with the derivation of equatorial offset angle, the
9 following explanation is based on rectangular projections of
10 the field of view of the various equatorial and polar
11 cameras. In actual use, the rectangular projections do not
12 produce rectangular fields of view on sphere 110. Thus,
13 many small inaccuracies exist in the following calculations
14 of the number of polar cameras required for complete
15 coverage. However, as long as the estimated number is not
16 very close to the next greater integer these small
17 inaccuracies can be ignored. For clarity, camera system
18 400 is not shown in Figs. 5(c) and 5(d). Fig. 5(c) is a
19 view of the XZ plane from the perspective of looking down
20 the Y axis with the negative Y axis coming out of the page.
21 The intersection of sphere 110 with the XZ plane is shown as
22 circle 110_1 in Fig 5(c). Vertical field of view 440_V is
23 marked by rays 565 and 555. As explained above, vertical
24 field of view 510_V of polar camera 510 must overlap
25 vertical field of view 440_V. For clarity overlapping
26 portions of vertical fields of view 440_V and 510_V are
27 omitted in Fig. 5(c). Fig. 5(d), which is drawn from the
28 perspective looking down from the Z axis with the positive Z
29 axis coming out of the page, shows a circle 110_2 which
30 corresponds to intersection of sphere 110 with the XY plane.
31 Fig. 5(d) also shows a circle 110_3 which corresponds to the
32 intersection of sphere 110 with a plane containing the

1 intersection of ray 565 with sphere 110 and parallel to the
2 XY plane. Horizontal field of view 510_H is marked by rays
3 585 and 595. The radius of circle 110_3 is smaller than the
4 radius of circle 110_2, which is defined to be equal to one.
5 Specifically, the radius of circuit 110_3 is equal to the
6 cosine of angle 547 (Fig. 5(c)). Angle 547 is equivalent to
7 half of vertical field of view 440_V of equatorial camera
8 440. Although angular field of view has been used above to
9 determine the number of equatorial cameras, angular field of
10 view is actually a proxy for arc length coverage. However,
11 because sphere 110 is defined to have a radius of one, arc
12 length and angular field of view are equivalent measures for
13 equatorial cameras. However, for polar cameras the actual
14 radius of the sphere for horizontal field of view is less
15 than one. Thus, the angular horizontal field of view is not
16 a direct proxy for arc length. Therefore, the horizontal
17 field of view of polar cameras must be divided by the radius
18 of sphere 110_3, i.e. the cosine of half of vertical field
19 of view 440_V. Thus, for an embodiment of camera system 400
20 using both equatorial cameras and polar cameras having a
21 vertical field of view of approximately 76 degrees and a
22 horizontal field of view of approximately 104 degrees, the
23 number of polar cameras necessary for complete environment
24 coverage is an integer greater than or equal to 360
25 multiplied by cosine of 38 degrees divided by 104 degrees
26 (i.e. $360 * \cos(38)/104$ equals approximately 2.737).
27 Therefore, in this embodiment three polar cameras are used
28 in the first plurality of polar cameras.

29 As explained above, the derivation of equatorial offset
30 angles and the estimated number of polar cameras assumed
31 that the fields of view of the equatorial and polar cameras
32 are aligned with the XY plane. However, some embodiments

1 the present invention includes cameras that are rotated
2 along the optical axis of the camera. Rotation along the
3 optical axis in many cases may allow complete coverage in
4 situations where having all fields of view aligned with the
5 XY axis may fail to provide complete coverage. Figs. 6(a)-
6 6(c) illustrates some benefits that may be obtained from
7 rotation of the field of view. For clarity, Figs 6(a)-6(c)
8 use rectangular projection; however, as explained above in
9 actual use, the rectangular projections do not produce
10 rectangular fields of view on sphere 110. However, the
11 inaccuracies introduced by this simplification do the
12 greatly diminish benefits being illustrated. Specifically,
13 in Fig. 6(a) a field of view 610_F and a non overlapping
14 field of view 620_F are shown. However, as illustrated in
15 Fig. 6(b), by rotating field of view 610_F, field of view
16 610_F can be made to overlap field of view 620_F.
17 Additional rotated fields of view such as field of view
18 640_F can also be used for complete coverage of the
19 environment. Fig. 6(c) shows a rotated field of view 640_F
20 with a field of view 650_F. By rotating field of view
21 640_F, the effective horizontal field of view for field of
22 view 640_F is increased. The increase of increased
23 effective horizontal field of view is illustrated by field
24 of view 640_F fully encompassing the top side of field of
25 view 650_F. In general, the use of rotated field of views
26 provide a mixture of benefits and additional complications.
27 The use of rotated field of views can be greatly simplified
28 by using a 3-D projection system such as Powerstitch™ to
29 insure complete coverage of the environment.

30 As illustrated in Fig. 7, camera system 400 also
31 includes a second plurality of polar cameras. Specifically,
32 the second plurality of polar cameras includes polar cameras

1 710, 720 and 730 Fig. 7 is drawn from the perspective of
2 looking down the X axis with the negative X axis coming out
3 of the page. Polar cameras 710, 720, and 730 face radially
4 outward and are tilted below the XY plane by a equatorial
5 offset angle. The equatorial offset angle is dependent on
6 the vertical field of view the equatorial cameras and the
7 polar cameras. Although, camera system 400 includes three
8 polar cameras in both the first plurality and the second
9 plurality of polar cameras, other embodiments of the present
10 invention may include differing numbers of polar cameras in
11 the first plurality and the second plurality of polar
12 cameras. Furthermore, some embodiments of the present
13 invention may include a single polar camera below the XY
14 plane.

15 In the above-described manner, efficient outward facing
16 camera systems are made possible. Specifically, an outward
17 facing camera system in accordance with embodiments of the
18 present invention has better utilization of the image data
19 from each of the cameras than convention camera systems.
20 Thus, a camera system in accordance with the present
21 invention can use a fewer number of cameras and still
22 provide higher resolution environment maps than conventional
23 camera systems. The various embodiments of the structures
24 and methods of this invention that are described above are
25 illustrative only of the principles of this invention and
26 are not intended to limit the scope of the invention to the
27 particular embodiments described. For example, in view of
28 this disclosure, those skilled in the-art can define other
29 equatorial cameras, polar cameras, equatorial offset angles,
30 equatorial adjacent angles, equatorial tilt angles, polar
31 adjacent angles, vertical fields of view, horizontal fields
32 of view, and so forth, and use these alternative features to

1 create a method or system according to the principles of
2 this invention. Thus, the invention is limited only by the
3 following claims.

1
2
3 CLAIMS

4 What is Claimed is:

5
6 1. An outward facing camera system comprising:
7 a plurality of equatorial cameras distributed
8 evenly about an origin in a plane; and
9 a plurality of polar cameras coupled to the
10 equatorial cameras and tilted above the plane.
11

12 2. The outward facing camera system of Claim 1,
13 wherein the equatorial cameras face radially outwards from
14 the origin.
15

16 3. The outward facing camera system of Claim 1,
17 wherein the polar cameras face radially outwards from the
18 origin.
19

20 4. The outward facing camera system of Claim 1,
21 wherein a first equatorial camera is offset approximately 90
22 degrees from a second equatorial camera.
23

24 5. The outward facing camera system of Claim 1,
25 wherein each equatorial camera is offset from an adjacent
26 equatorial camera by the same equatorial adjacent angle.
27

28 6. The outward facing camera system of Claim 1,
29 wherein each of the polar cameras is tilted out of the plane
30 by an equatorial offset angle.
31

1 7. The outward facing camera system of Claim 6 wherein
2 the equatorial offset angle is in the range of 52 to 76
3 degrees inclusive.

4
5 8. The outward facing camera system of Claim 1,
6 wherein the plurality of equatorial cameras outnumber the
7 first plurality of polar cameras.

8
9 9. The outward facing camera system of Claim 1,
10 wherein each of the polar cameras is separated by a polar
11 adjacent angle equal to approximately 120 degrees.

12
13 10. The outward facing camera system of Claim 1,
14 wherein a vertical field view of a first equatorial camera
15 is equal the vertical field view of a second equatorial
16 camera.

17
18 11. The outward facing camera system of Claim 1,
19 wherein a horizontal field view of a first equatorial camera
20 is equal the horizontal field view of a second equatorial
21 camera.

22
23 12. The outward facing camera system of Claim 1,
24 wherein a vertical field view of a first polar camera is
25 equal the vertical field view of a second polar camera.

26
27 13. The outward facing camera system of Claim 1,
28 wherein a horizontal field view of a first polar camera is
29 equal the horizontal field view of a second polar camera.

30

1 14. The outward facing camera system of Claim 1,
2 wherein a vertical field of view of a polar camera is equal
3 to the vertical field of view of a equatorial camera.

4
5 15. The outward facing camera system of Claim 1,
6 wherein a horizontal field of view of a polar camera is
7 equal to the horizontal field of view of a equatorial
8 camera.

9
10 16. The outward facing camera system of Claim 1,
11 further comprising a polar camera coupled to the equatorial
12 cameras and tilted below the plane.

13
14 17. The outward facing camera system of Claim 16,
15 wherein the polar camera is perpendicular to the plane.

16
17 18. The outward facing camera system of Claim 1,
18 further comprising a second plurality of polar cameras
19 coupled to the equatorial cameras and tilted below the
20 plane.

21
22 19. The outward facing camera system of Claim 1,
23 wherein each of the equatorial cameras and each of the polar
24 cameras is a video camera.

25
26 20. The outward facing camera system of Claim 1,
27 wherein a polar camera has a vertical field of view which
28 overlaps a vertical field of view of an equatorial camera.

29
30 21. The outward facing camera system of Claim 1,
31 wherein the plurality of polar cameras are tilted by the
32 same equatorial offset angle.

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22. The outward facing camera system of Claim 1,
having four equatorial cameras in the plurality of
equatorial cameras and three polar cameras in the first
plurality of polar cameras.
23. The outward facing camera system of Claim 22,
further comprising a second plurality of three polar cameras
tilted below the plane.
24. A outward facing camera system comprising:
a first camera;
a second camera coupled to and adjacent to the
first camera, wherein the first camera and the second
camera are offset by a first offset angle; and
a third camera coupled to and adjacent to the
first camera, wherein the first camera and the third
camera are offset by a second offset angle differing
from the first offset angle.
25. The outward facing camera system of Claim 24,
wherein the first offset angle is approximately 90 degrees.
26. The outward facing camera system of Claim 26,
wherein second offset angle is in the range of 52 to 76
degrees inclusive.
27. The outward facing camera system of Claim 24,
further comprising a fourth cameras coupled to and adjacent
to the third camera; wherein the third camera and the fourth
camera are offset by a third offset angle.

1 28. The outward facing camera system of Claim 27,
2 wherein the third offset angle is approximately 120 degrees.

3

4 29. An outward facing camera system comprising:
5 a plurality of equatorial cameras distributed
6 evenly about an origin in a plane; and
7 a plurality of polar cameras in operative relation
8 to the equatorial cameras and tilted above the plane.

9

10 30. The outward facing camera system of Claim 29,
11 wherein the equatorial cameras face radially outwards from
12 the origin.

13

14 31. The outward facing camera system of Claim 29,
15 wherein the polar cameras face radially outwards from the
16 origin.

17

18 32. The outward facing camera system of Claim 29,
19 further comprising a second plurality of polar cameras in
20 operative relation to the equatorial cameras and tilted
21 below the plane.

22

ERT-008-0340

Roy T. Hashimoto

Asymmetrical camera systems, which are adapted to utilize a greater proportion of the image data from each camera as compared to symmetrical camera systems, are disclosed. Specifically, an outward facing camera system in accordance with one embodiment of the present invention includes a plurality of equatorial cameras distributed evenly about an origin point in a plane. The outward facing camera system also includes a first plurality of polar cameras tilted above the plane. Furthermore, some embodiments of the present invention include a second plurality of polar cameras tilted below the plane. The equatorial cameras and polar cameras are configured to capture an complete coverage of an environment.

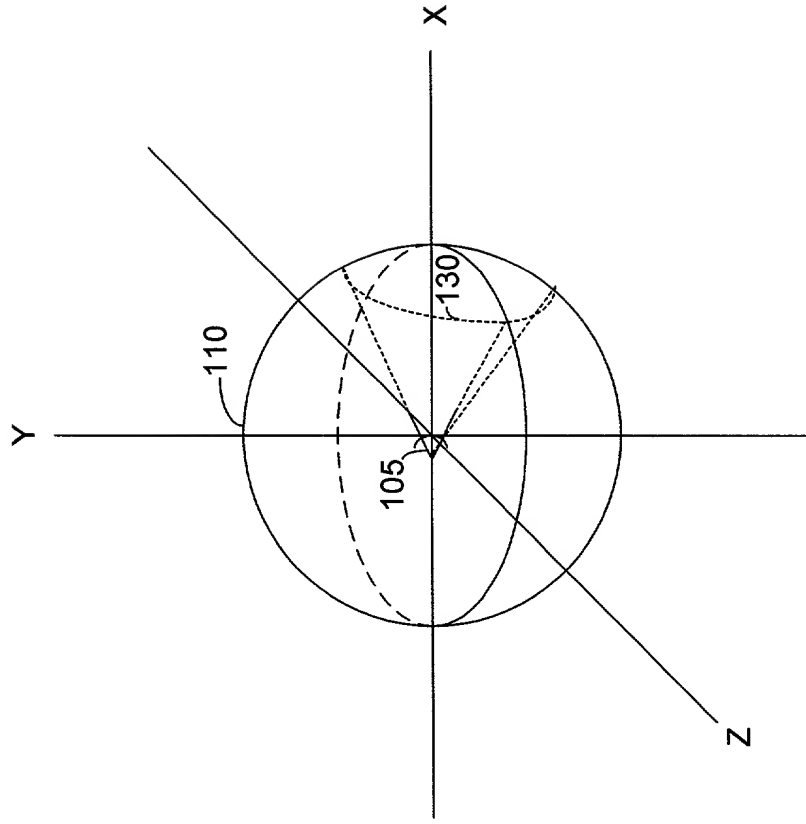


Fig. 1 (Prior Art)

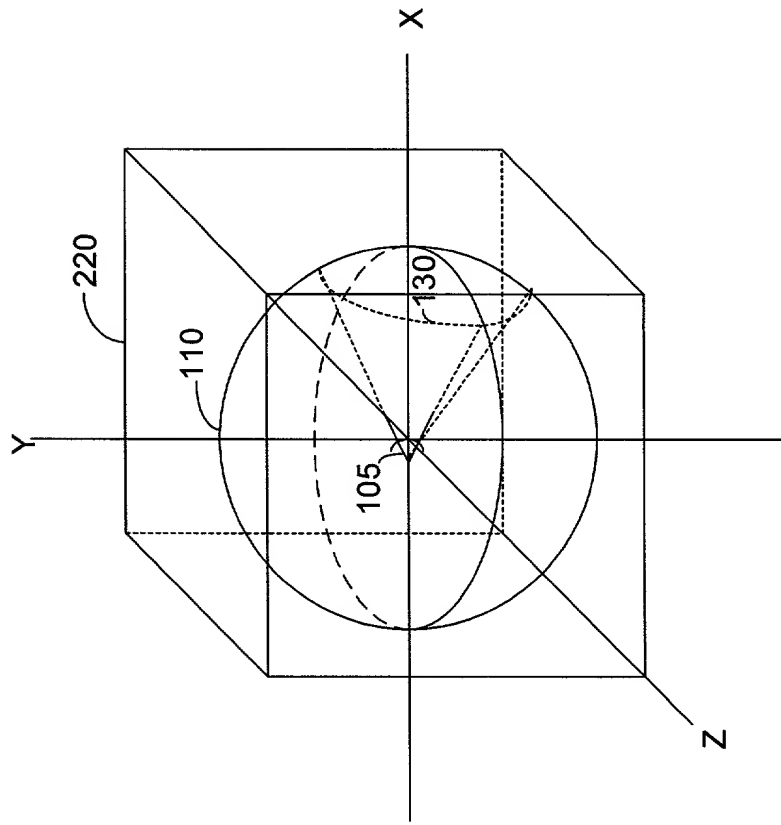


Fig. 2(a) (Prior Art)

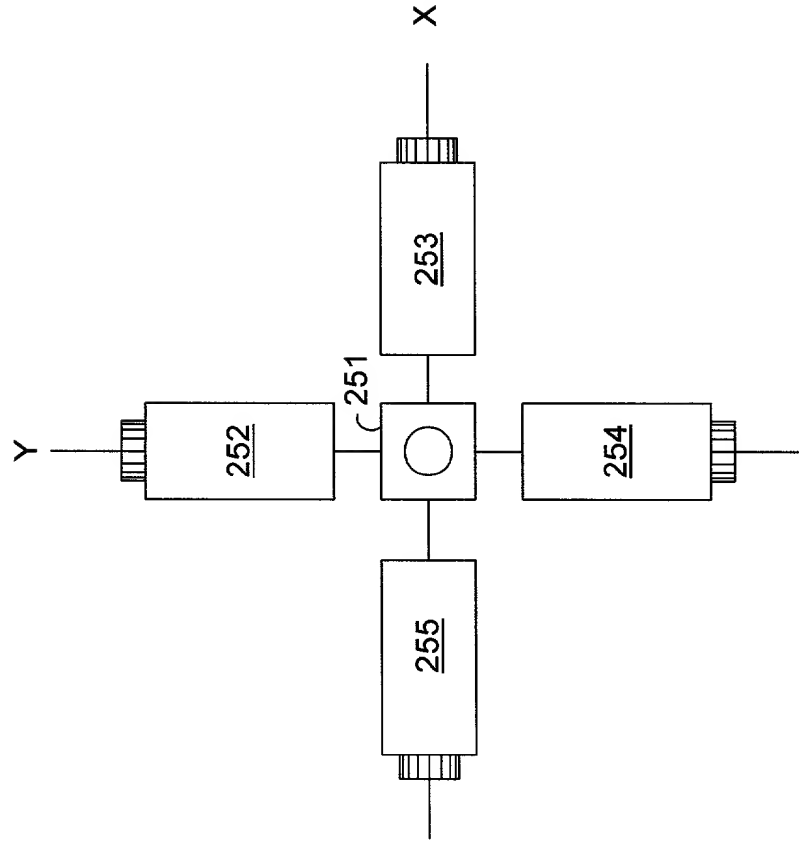


Fig. 2(b) (Prior Art)

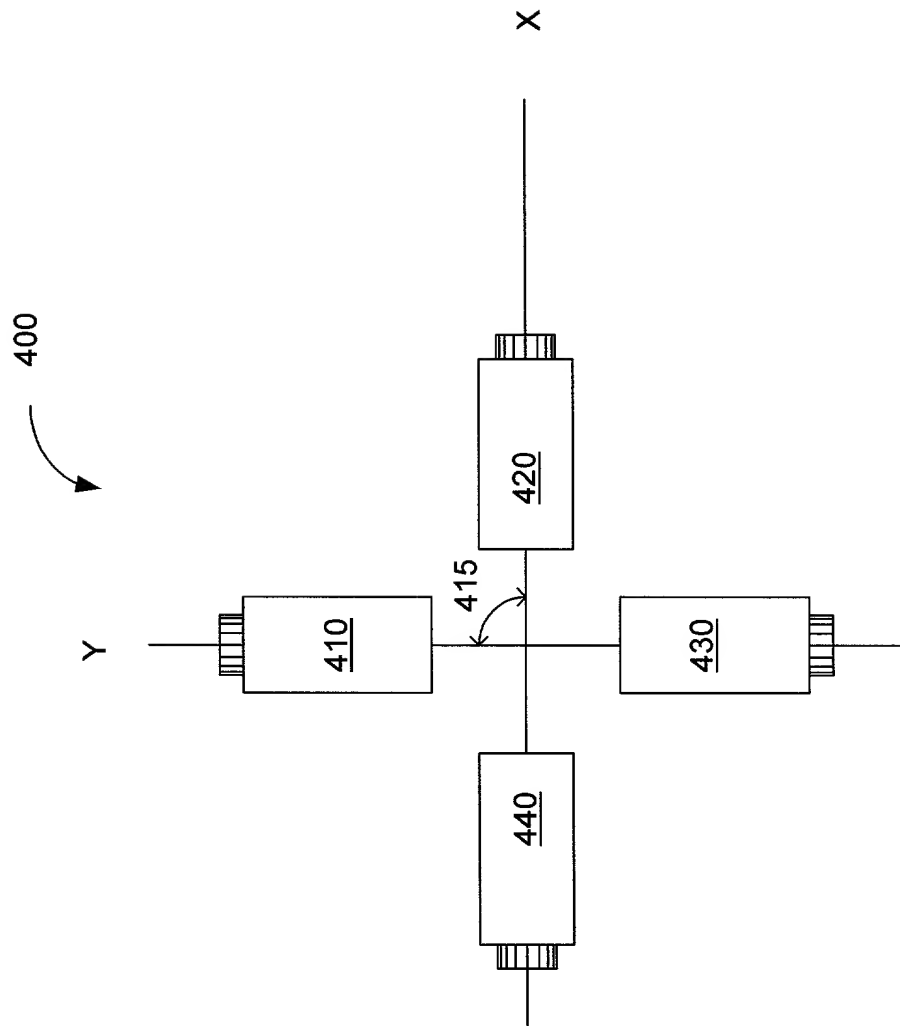


Fig. 4

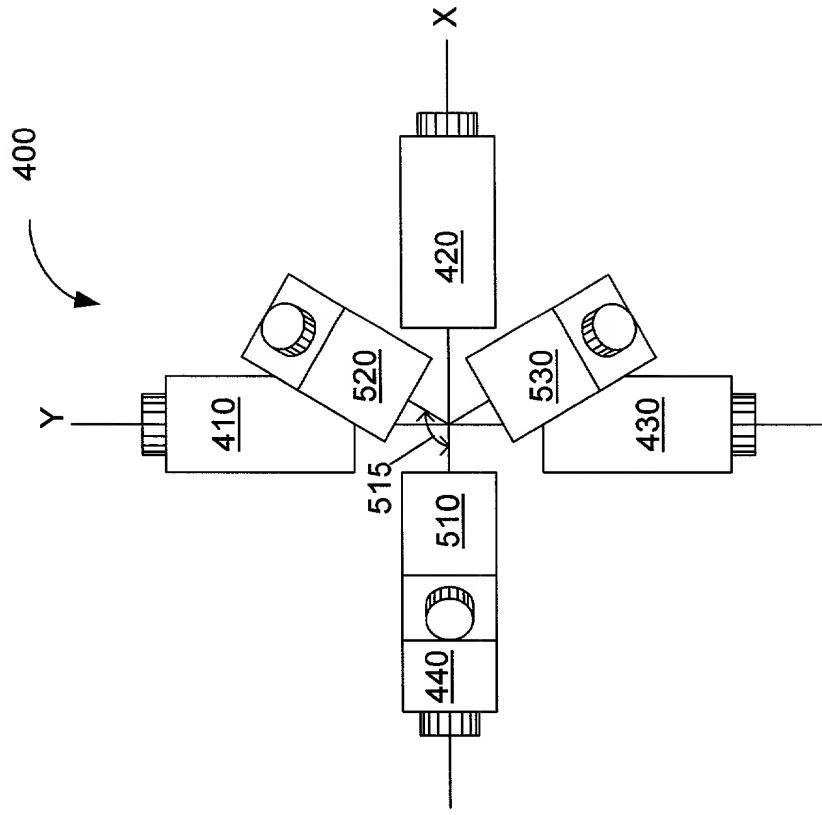


Fig. 5(a)

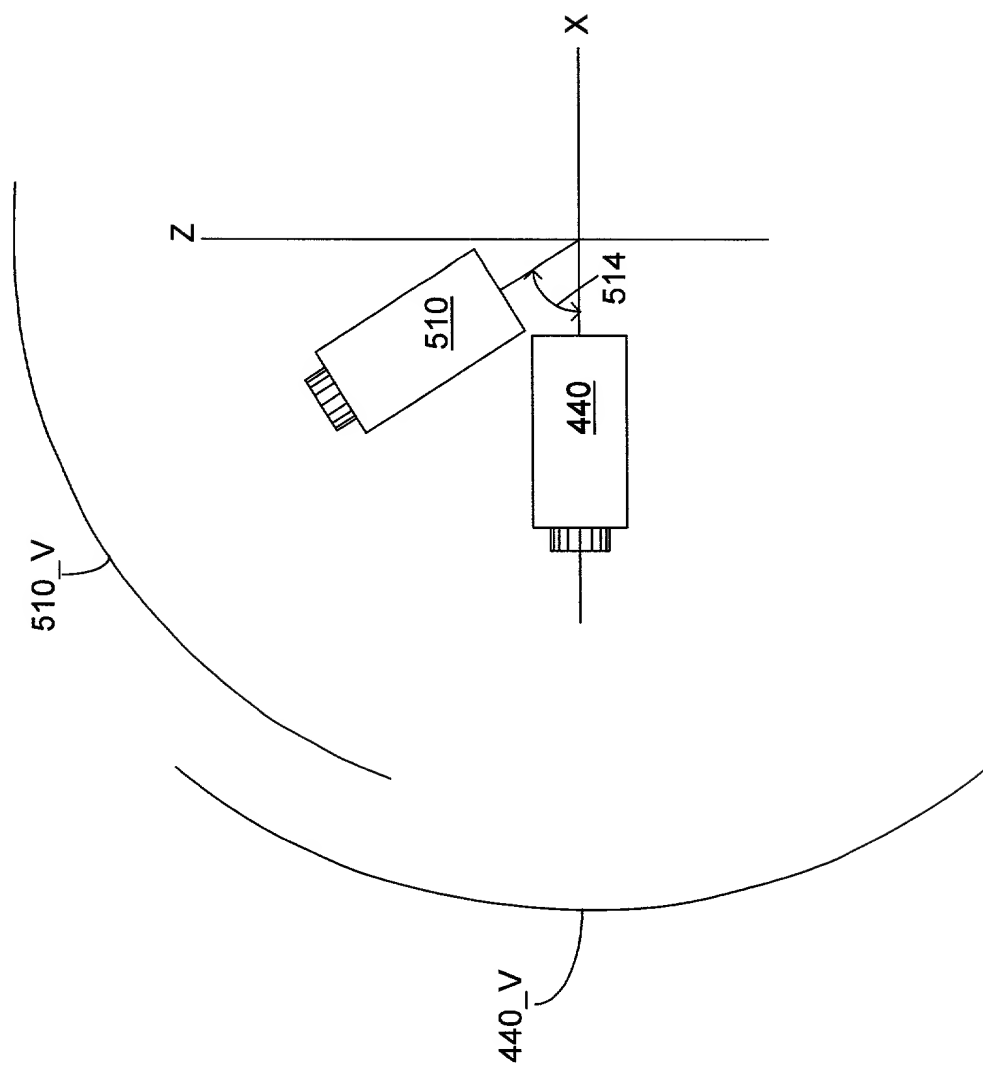


Fig. 5(b)

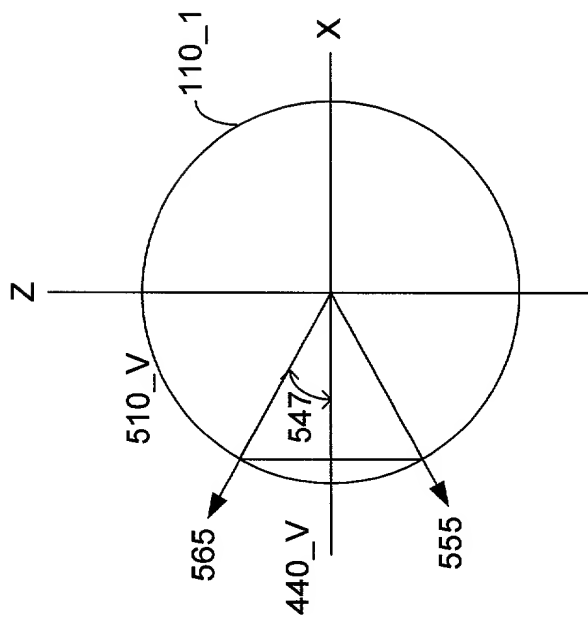


Fig. 5(c)

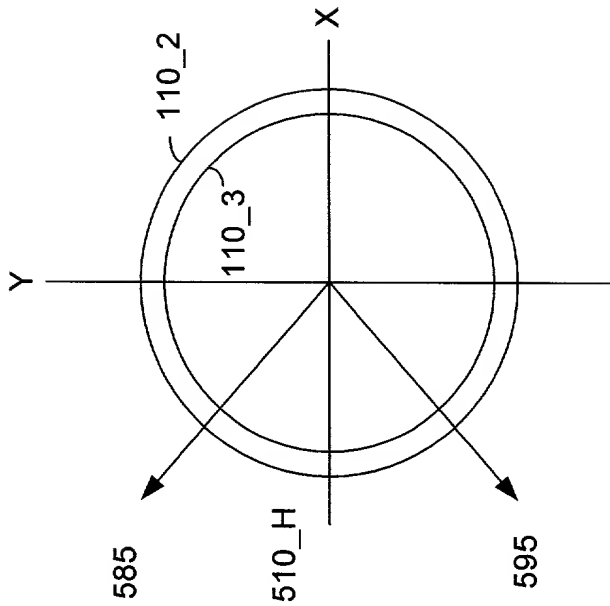


Fig. 5(d)

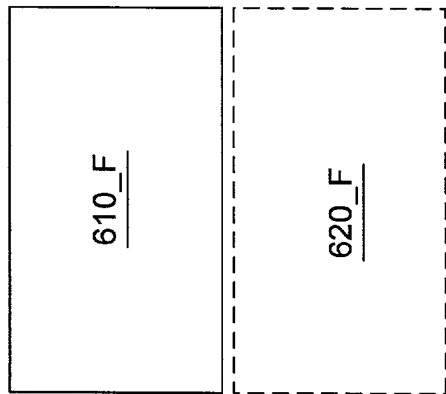


Fig. 6(a)

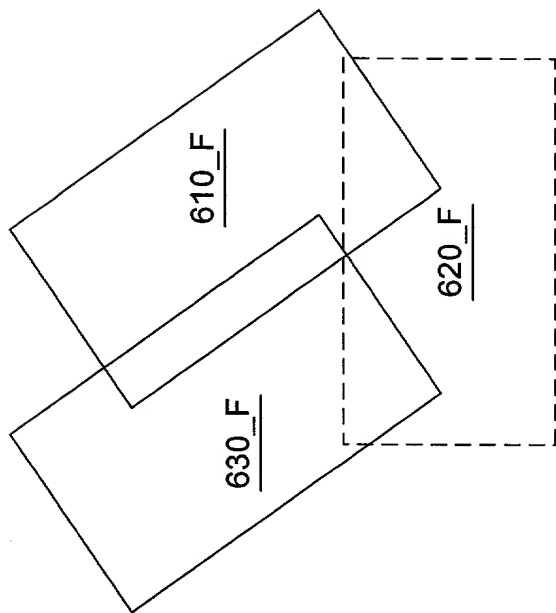


Fig. 6(b)

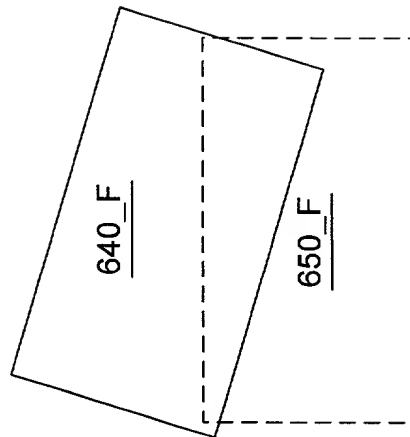


Fig. 6(c)

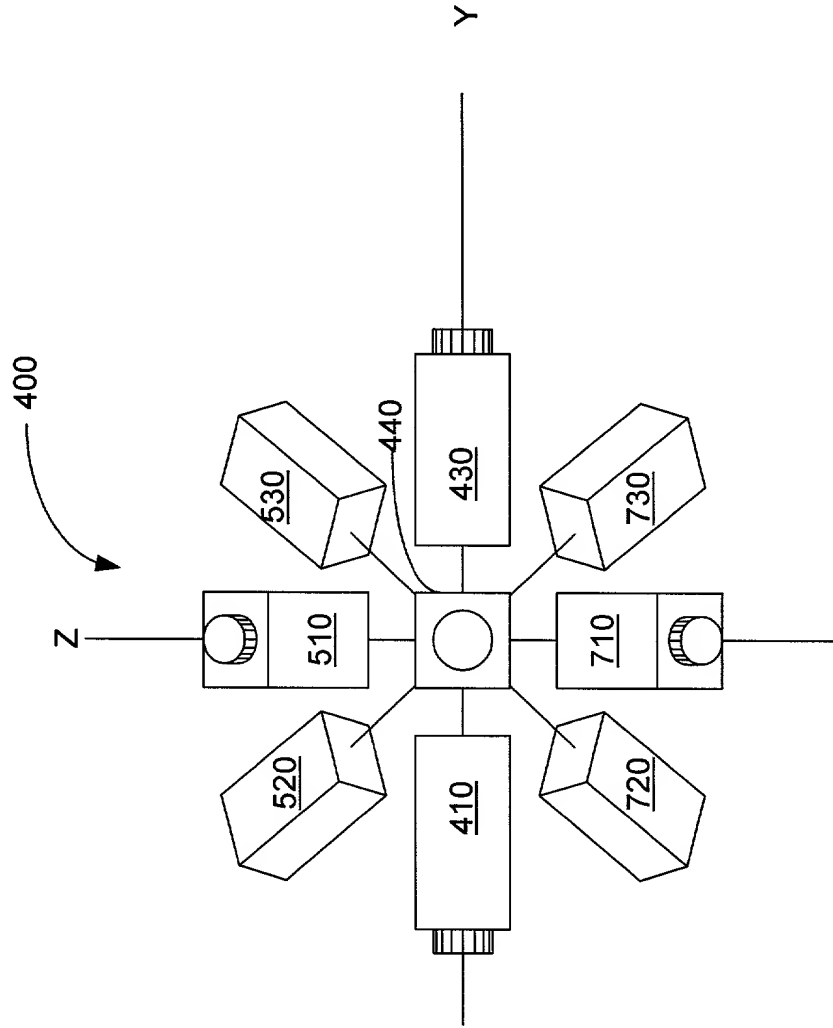


Fig. 7